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Abstract

This article demonstrates that "The Raven Legend," a Haida myth transcribed by Franz Boas in 1888, is full of (ethno)mathematical concepts that Haida society used to make sense of the natural, real world. Calculus can be used to model several segments of the story since the narrative relied heavily on ideas that a mathematician would identify as the concepts of infinity and mathematical limits.

Keywords: Haida, ethnomathematics, mathematics, magic realism.

1. Introduction

This article highlights the connections between mathematics and "The Raven Legend," the Haida myth first transcribed by pioneering anthropologist Franz Boas in 1888. The aim of the article is to address the following two points:

(i) Parts of the legend narrative may be related to a variety of mathematical concepts, some relatively complex; and

(ii) Mathematical models can be used to describe both the real- and fantasy-world elements in this particular Haida myth.

Boas visited Haida Gwaii, the traditional territory of the Haida people,[1] in the summer of 1888 during his second trip to British Columbia, Canada.

[1] It is outside the scope of this article to elaborate on the history of Haida, their culture and traditions, or the damage that colonization brought to the Haida people and their way of life. To learn more about this ancient people, see [7, 15, 16].

Scholars have dated a number of archeological sites on Haida Gwaii, an archipelago off the northern Pacific coast of British Columbia, to about 8,000 years ago [13]. In the 17^{th} century, the Haida civilization began to experience a period of growth and prosperity, and in the early 18^{th} century, "some Haida families reacted to growing pressures on the population of the villages around North Island by beginning to move to the islands of what is now known as the Prince of Wales archipelago in southeast Alaska" [11]. Members of this newly established community became known as Kaigani Haida. In his field notes, Boas identifies the primary source of "The Raven Legend" discussed in this article as "an old Kaigani."

Boas was just thirty years old during his second visit to Haida Gwaii and at the beginning of a long career that would establish him as "the founder of the relativistic, culture-centred school of American anthropology that became dominant in the 20^{th} century" [18]. But Boas's most significant contribution to the study of the Haida probably occurred a dozen years later when his student John R. Swanton, influenced by Boas's earlier work, arrived at Haida Gwaii to spend the next three years listening and recording "one of the world's richer classical literatures, embodying one of the world's great mythologies" [7, page 13].

Boas's groundbreaking monograph *Indian Myths & Legends from the North Pacific Coast of America* was first written in German and published in 1895 as *Indianische Sagen von der Nord–Pacifischen Küste Amerikas*. (It would take more than a century for the English translation of this book to appear, see [5].) The Haida section of the book contains nine stories, with eight of them featuring Raven as the primary character.[2] "The Raven Legend" is the first story in this sequence. Considering that the Haida did not have a written script and that they maintained an oral history, passing down histories and legends through generations, it is likely that Boas was the first to transcribe "The Raven Legend."

[2] The significance of the Raven character to the indigenous people of the Pacific Northwest will be celebrated with a new postage stamp scheduled to be issued by the United States Postal Service on July 30, 2021; see https://store.usps.com/store/product/buy-stamps/raven-story-S_478004, last accessed on July 15, 2021.

"The Raven Legend," with its 485 words in English version [5, pages 601–602], represents a true infinitesimal in Boas's oeuvre of about 650 books and articles [10]. Nonetheless, it is a dynamic, event-rich narrative where reality and the supernatural are closely intertwined.

Here is a short synopsis of "The Raven Legend" (in my words):

> NEnkilstlas, the uncle of Raven, killed all of his sister's many sons. After watching her mourning for long time, a seagull told the sister to swallow four stones. She obeyed and later gave birth to four more sons. The boys sought to revenge their siblings. They found a way to make NEnkilstlas so angry that he "put on his big hat, from which a stream of water started gushing into the house immediately." The oldest son transformed into Raven, flew upwards, and blocked the hat from reaching the sky, thereby drowning NEnkilstlas.

I underscore that this article is based on an English translation of the German version of the transcript of the narration in the Haida language by an old Kaigaini that Boas heard in 1888. It is likely that through the translation process some aspects of the Haida myth were altered. In a different context, Kathy Bedard Sparrow of the Haida Nation warned that "[u]nderstanding a cultural system by outsiders may easily go astray and in fact be perpetuated within a scholarly tradition" [15, page 216].

Nevertheless, Boas's account is a suitable starting point for examining the Haida myth because his transcription occurred at an early point of contact between the Haida and Europeans, and because the anthropologist transcribed versions of the legend in interviews with members of numerous indigenous nations from the northern Pacific Coast: as Robert Bringhurst tells us, "Boas studied over fifty different versions of the Raven story in preparing the elaborate study of Northwest Coast mythology that he published in 1916" [7, page 1180].

The combination of real and magical in "The Raven Legend" may lead the reader to recall Salman Rushdie's reflections about the literary genre known as magic realism:

> The trouble with the term "magic realism", *el realismo mágico*, is that when people say or hear it, they are really hearing or saying only half of it, "magic," without paying attention to the other half, "realism." But if magic realism were just magic, it wouldn't matter. It would be mere whimsy — writing in which, because anything can happen, nothing has effect. It's because the magic in magic realism has deep roots in the real, because it grows out of the real and illuminates it in beautiful and unexpected ways, that it works. [14]

This article follows Rushdie's guidance and uses mathematics to look for the realism in "The Raven Legend," an undoubtedly magical story. Furthermore, this article seeks to demonstrate that "The Raven Legend" uses magical narrative elements to engage with complex and very real mathematical concepts. More specifically, in this article, I argue that "The Raven Legend" reflects (ethno)mathematics in its clear use of counting, locating, measuring, and designing, but also in its use of the infinitesimal concept.

2. Ethnomathematics as a Method

In the mid-1980s, Ubiratan D'Ambrosio, a Brazilian mathematics educator and historian of mathematics,[3] defined ethnomathematics as "the mathematics which is practiced among identifiable cultural groups, such as national-tribal societies, labour groups, children of certain age bracket, professional classes, and so on" [9, page 45]. In contrast, academic mathematics was defined as "mathematics which is taught and learned in schools." In addition, D'Ambrosio argued that mathematics includes "apart from the Platonic ciphering and arithmetic, mensuration and relation of planetary orbits, the capabilities of classifying, ordering, inferring and modelling." In this article, I use the term *mathematics* in the sense of D'Ambrosio's definition of ethnomathematics; i.e., as a term that includes "a very broad range of human activities which, throughout history, have been expropriated by the scholarly

[3] This issue of the *Journal of Humanistic Mathematics* includes "Ubiratan D'Ambrosio: Celebrating His Life and Legacy" by Milton Rosa and Daniel Clark Orey, a heartfelt tribute to D'Ambrosio, who passed away in May 2021. See https://scholarship.claremont.edu/jhm/vol11/iss2/26.

establishment, formalized, codified and incorporated into (...) academic mathematics" but which also "remain alive in culturally identified groups and constitute routine in their practices" [9, page 45].

Marcelo C. Borba, another Brazilian mathematics educator, reflected that the ethno- in ethnomathematics "should be understood as referring to cultural groups, and not to the anachronistic concept of race," and that mathematics "should be seen as a set of activities such as ciphering, measuring, classifying, ordering, inferring and modelling" [6, page 40].[4] In his view, "even the mathematics produced by professional mathematicians can be seen as a form of ethnomathematics because it was produced by an identifiable cultural group and because it is not the only mathematics that has been produced." Borba suggested a visualization of ethnomathematics as a forest "in which each tree would be considered as a different expression of ethnomathematics, socio-culturally produced" [6, page 41]. This visualization of ethnomathematics as a forest will lead to the visualization of a crucial component of my analysis of "The Raven Legend" in this article.

Bartlett, Marshall, Marshall, and Iwama [2, page 293, Figure 10.2] offer a visualization of the concept of "two-eyed seeing" as the image of two trees extending their roots into a handshake—the title of the image is "Trees Holding Hands." Elder Albert Marshall of the Mi'kmaw Nation explains that "Two-Eyed Seeing refers to learning to see from one eye with the strengths of indigenous knowledges and ways of knowing and from the other eye with the strengths of Western knowledges and ways of knowing and to using both these eyes together, for the benefit of all" [2, page 295].

In the spirit of "two-eyed seeing", I intend to demonstrate that, in Borba's forest of ethnomathematics, the tree labelled "Haida Ethnomathematics" and the tree labelled "Pure Mathematics" lock hands through "The Raven Legend". In doing so, I offer a classification of the "mathematical terms" contained in the story, including terms that refer to various quantities, including their approximations, and orientation in space or time, among others.

[4] In his article, Borba also refers to Bishop's argument [3] that six fundamental activities — counting, locating, measuring, designing, playing, and explaining — were necessary and sufficient for the development of mathematical knowledge.

I also highlight, for the mathematician's eye, the evident notions of unlimited sources and infinitesimal quantities in "The Raven Legend."

Still, as a professional mathematician writing this article, I am fully aware of Marcia Ascher's warning from [1, page 204]: "As with any work in ethnomathematics, however, what I see and what I can express is confined to ideas in some way analogous to my own."

3. The Raven

The chapter in [5] containing "The Raven Legend" appears on pages 601 to 608, and has eight parts, each an independent story, connected by the protagonist, the Raven.

The Raven has a central role in Haida mythology. As the Bill Reid Foundation explains, in relation to a 1980 sculpture by Bill Reid titled *The Raven and the First Men* by Bill Reid:

> In Haida culture, the Raven is the most powerful of mythical creatures. His appetites include lust, curiosity, and an irrepressible desire to interfere and change things, and to play tricks on the world and its creatures. [4]

This role has been discussed in detail in [7] and it represents a recurring theme there. Bringhurst, a Canadian poet and author, claims that Ghandl, a Haida myth teller, explained to Boas's student Swanton "how the spirit–beings as well as human beings are divided into Raven and Eagle sides." Ghandl also explained that "the Raven is a raven and a Raven — a member of the raven species and the Raven side — and the Eagle is an eagle and an Eagle; but no one — neither a human nor a myth creature — is the leader of a species or a nation or a side." [7, page 67]

In the more general context of "Raven Myths in Northwestern North America and Northeastern Asia," Ann Chowning, an American anthropologist, explains that Raven "combines the attributes and abilities of a bird and a man, and is characterized by an insatiable appetite." Furthermore, Raven plays "the triple role of transformer, trickster, and dupe, simultaneously or alternately" [8, page 1].

Thus it is natural that in "The Raven Legend," Raven is both a human and a mythical creature (as per Bringhurst), with the abilities of a bird and a man, and plays the roles of transformer and trickster (as per Chowning).

4. The Words

Mathematics, in its various forms, is an important part of the Haida way of life as illustrated by Kanwal Inder Singh Neel, a Canadian math educator. Neel, who uses the term "numeracy practices" [12, page 80], provides an extensive analysis of applications of a wide range of mathematical concepts used by the community of Haida Gwaii. The purpose of this article is somewhat different: its aim is to, by using what Elder Albert Marshall calls "the other eye," i.e. the eye of a trained mathematician, point out the connection between "The Raven Legend" and pure mathematics: the study of the basic concepts and structures that underlie mathematics.

Table 1 on the next page illustrates the words and phrases in "The Raven Legend" that are also used in (pure) mathematics to describe properties of mathematical objects, including sets of mathematical objects, as well as the relationship between mathematical objects. Phrases that indicate change, the main topic of study in calculus, are also included. To underline their mathematical interconnections, the words and phrases are clustered based on their common relationship with the particular mathematical concept.

The total count of the words listed in Table 1 is 133, which represent slightly more than 25% of all words used in the English translation of "The Raven Legend." This supports the argument that the myth, in Rushdie's words, "has deep roots in the real." Here we assume reality in a broad sense and consider its natural, observable component.

If, for the sake of simplicity, one takes each phenomenon from the category "change/motion" as the numerical value at time t, with respect to the fixed reference point at time $t = 0$, then the majority of the phrases in this category used in "The Raven Legend" can be expressed in terms of the values of a function $f(t)$ or its derivative $f'(t)$. This means that various segments of the myth may be represented by mathematical models. In Table 2 this idea is further explored.

Mathematical Concept	Words and Phrases used in the Raven legend
quantity	four (2 times), nobody (2), one (3), third time
qualifier	all (2), always, each, every, someone
approximation/quantifier	big, little while, long time, low, many, often, quickly (2), short time
relation	eldest, match, opposite
object	arrow, bow, hole, pieces, ring, whirlpool
object properties/patterns	covered, ornamented, polished, round, sharp, smoothed, smoothly, tiny
direction in space	against, down, 'he braced his feet against the hat, his beak against the sky', into, over, reached, returned, skywards, through, under
direction in time	after, again, already, continued, soon (2), thereupon, when
change/motion	flew away, get up (3), go down, gone out, grew, grew correspondingly higher with the rising water, grow up, stream of water started gushing, kept (2), lay down, looked up, loss, put on (2), sent back to, swam away, threw off, transformed, warm them, water rose, water rose still higher, went down, went into, went out

Table 1: Correspondences between concepts and phrases.

5. The Hat

"The Raven Legend" climaxes when the oldest boy sheds his human skin, transforming into Raven, and defeats his uncle in battle while his mother also changes her physical form and escapes:

> [NEnkilstlas] went into the house, sat down opposite the door and put on his big hat, from which a stream of water started gushing into house immediately. The eldest boy put on his duck skin and transformed himself into, Yētl, Raven, who flew skywards when the water rose. His mother put on the skin of a diver [a loon] and swam away. The hat of NEnkilstlas grew correspondingly higher with the rising water. At last, Yētl reached the sky and when the water rose still higher, he braced his feet against the hat, his beak against the sky, and so succeeded in drowning NEnkilstlas. [5, pages 601–602]

In this passage, a mathematician can recognize the ideas of the function (transformation), infinity, the infinitesimal, and the limit. These ideas are fundamental for the branch of mathematics called mathematical analysis.

Phrase	**Mathematical model – description**	**Mathematical model – notation**
get up	a function of time t that increases from 0 to some A, $A > 0$.	$f(t_0) = 0, f(t_1) = A$, $f'(t) > 0$ for $t \in (t_0, t_1)$
go (went) down	a decreasing function of time t	$f'(t) < 0$ for $t \in (t_0, t_1)$
grew	a function of time t that has increased from a to b, $a < b$	$f(t_0) = a$, $f(t_1) = b$ with $t_0 < t_1$ and $a < b$
grew correspondingly higher with the rising water	Two rates of change are directly proportional.	$f'(t) = kg'(t), k \geqslant 1$
gushing	a large total flux	$\int_S \mathbf{F} \cdot \mathbf{n} dS$
loss	The net change of a function is negative.	$\int_a^b f(t)dt < 0$
sent back	the distance function where velocity changes signs at some point in time	$f'(t') \cdot f'(t'') < 0$ for $t' \in (t_0 - \alpha, t_0)$ and $t'' \in (t_0, t_0 + \alpha)$, for some $\alpha > 0$
smoothly	a differentiable function	$f'(t)$ exists for $t \in (t_0, t_1)$
stream	fluid flow	non-linear system of partial differential equations
swam away	the distance function where velocity does not change signs	$f'(t) > 0$ or $f'(t) < 0$ for $t \in (t_0, t_1)$
put on, reached, threw off	the end position of a motion of an object in space	$f(b)$ for a function f defined on a (time) interval $[t_0, t_1]$
returned	a distance function with multiple zeros	$f : [0.T] \to \mathbb{R}$ with $f(0) = f(t_0) = 0$ for some $t_0 \in (0, T]$
rising water, water rose, rose still higher	an increasing function in time t	$f'(t) > 0$ for $t \in (t_0, t_1)$
transformed	the output of a function	$t \to f(t)$

Table 2: Phrases and corresponding mathematical models.

In mathematical analysis, the introduction of the concepts of a function, infinity, infinitesimal, and the limit bridge the gap between human biological senses and the level of abstraction required to better describe and understand certain aspects of reality. In the passage above, the narrator does something very similar. To describe a battle between new and old, an ongoing aspect of the reality, the narrator uses the essence of the concepts of a function, infinity, infinitesimal, and the limit to leave the real and enter the magical: humans transform into different creatures, objects appear to grow unstoppably, and only Raven's beak, an infinitesimal, prevents their attempt to reach the sky.

NEnkilstlas's hat is a source of an infinite amount of water. It can generate "a stream of water" that fills part of 3-dimensional space. And, as with the infinity of mathematical analysis, it does not lose this capacity through the process: an infinite amount has been taken away but an infinite amount remains.

For a student of mathematics, it does not come as a surprise that if part of the space bounded by the hat contains an infinite amount of water, as the narrator of "The Raven Legend" suggests, then there is enough water there to fill up the universe. Early in their studies of mathematical analysis, undergraduate students learn that there is a one-to-one correspondence between the whole 3-dimensional real space and its non-empty open subset, no matter how small it is. It seems reasonable to assume that the Haida narrator was not necessarily familiar with the formal representation of the mathematical concepts of infinity. Even under this assumption, the clarity and simplicity with which the idea of infinity is presented in "The Raven Legend" demonstrates that the Haida storyteller is describing, in their own way, the same phenomenon as the mathematician talking about infinity in a small open subset of space. Going a step further, for a mathematician the concept of infinity is undoubtedly both abstract and real. Correspondingly, in the Haida legend, the concept of infinity — a hat as a source of the unbounded amount of water — is both supernatural and real.

A possible reading of the story may be that for the narrator, in mathematical terms, the sky is the upper boundary of the universe and that the distance between the earth and the sky is finite. Both the distance between the top of the hat and the earth's surface as well as the level of water are growing as they approach the sky. The narrator relates the two rates of change, the rate of increase of the height of the hat, and the rate of increase of the level of water: "The hat of NEnkilstlas grew correspondingly higher with the rising water." But Yētl / Raven is faster; in other words, Raven's velocity is greater than the velocity of the top of the hat, and by bracing "his feet against the hat, his beak against the sky," he prevents the hat from reaching the sky. Thus, Raven's body, infinitesimal in comparison with the distance between the earth and the sky, prevents the hat from touching the sky.

This is exactly how we show that a limit does not exist: if I is a time interval, $H(t)$ the height of the top of the hat at time $t \in I$, S the distance between the sky from the earth, and $\varepsilon > 0$ the distance between Raven's feet and his beak, then

$$\text{for all } t \in I, \quad |H(t) - S| \geqslant \varepsilon \,.$$

And since the hat does not reach its intendent limit, just as in a failed mathematical proof, everything collapses and NEnkilstlas drowns.

6. Conclusion

"The Raven Legend" is full of (ethno)mathematical concepts that Haida society used to make sense of the natural, real world. Calculus can be used to model several segments of the story since the narrative relies heavily on ideas that a mathematician would identify as the concepts of infinity and mathematical limits.

And yet, "The Raven Legend" remains a magical story. In it, mathematics is used to connect the supernatural and real-world; or, in Rushdie's words, "the magic in magic realism has deep roots in the real." "The Raven Legend" is about the very human feelings of love, cruelty, grief, and anger, as well as about the world in which everything is quantified, exactly or approximately, and in which people and objects, most of the time, move in space and time in quite ordinary ways. At the same time, the narrator leaves no doubt that the supernatural rules that world: the magic powers of NEnkilstlas seem boundless. The final twist of the story, when an epsilon[5] overcomes infinity, triggers the very human notions of revenge and redemption.

The fact that mathematics can be used to model both the ordinary and the magical supports the claim that, paraphrasing Rushdie, one may obtain another possible description of mathematics:

> Mathematics, even in its most abstract forms, has deep roots in the real, because it grows out of the real and illuminates it in beautiful and unexpected ways.

Or, maybe, this is exactly what Raven, the Trickster, wants us to do: see mathematics everywhere.

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[5] The epsilon ε is commonly used in mathematical analysis to represent an infinitesimal quantity.

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